...SION ON IRRIGATION AND DRAINAGE

#311

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NEUVIEME CONGRES QUESTION 32.1

IRRIGATION SCHEDULING FOR OPTIMUM WATER MANAGEMENT*

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ABSTRACT

Irrigation scheduling is rapidly gaining acceptance as a valuable tool for developing an on-farm water management program. Irrigation scheduling develops the optimum timing and amounts of irrigation applications and provides the ability to manage the soil-moisture reservoir. Improving the timing and amounts of irrigation applied will reduce the adverse environmental effects of irrigated agriculture. Improved management of the soil-moisture reservoir directly benefits the irrigator economically. A computer is used to maintain a daily water budget, give the current status of the soil-moisture reservoir, and predict evapotranspiration for the next 14 days. Data required are basic soil-moisture properties, estimated rate of crop development, and daily climatic data. By applying these parameters as they individually and comprehensively relate to an irrigation project and the local cultural practices, an optimum irrigation schedule can be developed. This schedule gives attention to the many decision considerations that an irrigator needs to make in his day-to-day operation.

Irrigation scheduling is the "grass roots" level of water management, and the initial step of any comprehensive land and water management concept related to irrigated agriculture.

* Programme d'irrigation pour un emploi optimum.

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RESUME ET CONCLUSIONS

Les plans d'irrigation jouent un rôle important dans l'utilisation optima des ıx. En obtenant un minutage optimum, ainsi que les quantités exactes au nécessaire pour l irrigation, on contrôle les réservoirs chargés d'assu- l'humidification des sols. Comme le rapport atmosphère/humidité sols est une affaire compliquée, celui qui s'occupe d'une ferme irriguée t s'y entendre en teneur d'eau pour les sols, en météorologie, en équations ;/eau/plante, en hydraulique, en ce qui concerne les systèmes d'irrigation, si qu'en combinaisons de ces différents facteurs dans le système qu'il ise. Une des solutions à ces connaissances multiples consiste à employer professionnel des systèmes d'irrigation.

Le premier but d'un service d'irrigation consiste à fournir au directeur les ormations les plus récentes en ce qui concerne le contenu en eau des sols ır chacun des champs à des coûts réduits. Le but principal du service est permettre à celui qui dirige la ferme d'intensifier la production sans gmenter les dépenses accessoires.

En 1969, on a créé un programme de direction d'irrigation (IMS), dans districts A et B du projet Minidoka en Idaho. En 1973, le projet IMS té étendu à trois autres zones d'irrigation en Idaho, et le Bureau de Récla- ıtion a fourni l'emploi du temps pour 35.000 hectares (85.000 acres) de res irrigables. Le programme total du Bureau de Réclamation a porté : plus de 53.000 hectares (130.000 acres) en Idaho, Californie, Wyoming, xas, Colorado et Kansas.

Le Bureau des services d'irrigation permet à l'irrigateur de faire des ıéfices grâce à l'accroissement des récoltes, à une meilleure utilisation ou e diminution de la main-d'oeuvre, un meilleur emploi des eaux, et une ninution des pertes du sol en nitrates, ainsi que grâce à l'absence de ses en périodes de pointe et à une diminution des problèmes de drainage. : même, IMS rend service au district irrigué en diminuant la quantité :au utilisée, les drainages requis et les problèmes d'approvisionnement en ı. Le pays, l'état, la nation bénéficient des améliorations apportées sol par l'irrigation, l'utilisation de ressources naturelles, et l'absence ɜffets contraires sur l'environnement.

Grâce à l'application du programme de développement de l'IMS, le coût l'opération en 1973 a été de $1 par hectare ($ 4,50 par acre) pour les gions indiquées. L'expérience et les chiffres fournis montrent que pour de andes étendues l'irrigation s'établirait entre $ 2,50 à $ 5 par hectare ($ 1 à par acre) par an selon les services rendus.

Le Bureau de Réclamation fournit actuellement à l'irrigateur trois stèmes d'aide. Ce sont "Le guide en matière d'irrigation", "Méthode ;ricole", et "Champ par champ". Ces trois méthodes permettent à rrigateur de prendre la décision finale en ce qui concerne la quantité et le oment où il a besoin d'eau.

Le guide en matière d'irrigation indique les périodes d'irrigation pour s récoltes principales pour une région donnée en fonction de l'évaporation des teneurs en eau. Le guide est revu toute les semaines à partir des don- ;es climatiques obtenues d'une station centrale. Il indique les quantités d'eau à employer en moyenne par jour, et le total par semaine, ainsi que la totalité de l'eau usée jusqu'à présent et les prévisions pour la semaine suivante.

La méthode agricole est beaucoup plus complète que le Guide, mais donne à peu près les mêmes informations. Les chiffres fournis dans la Méthode agricole sont obtenus à partir d'informations visant une ferme irri- guée typique, tandis que le guide de l'irrigation représente une région irri- guée en général. La Méthode agricole comme le Guide requièrent de la part de l'irrigateur la tenue de renseignements exacts en matière de précipitations, d'irrigation, de quantités et d'emploi du temps.

La méthode "Champ par champ" fournit à l'irrigateur le contenu journalier en eau de chaque champ. Si des renseignements adéquats sont obtenus les quantités et le réglage peuvent être fournis.

La méthode "Champ par champ" offre à l'irrigateur un plan venant d'un ordinateur une fois ou deux fois par semaine qui est considéré "à la page", en ce qui concerne son programme d'irrigation. L'évaporation est prévue pour les 14 jours suivants et réévaluée pour chaque période d'irrigation. Ces prévisions sur l'évaporation sont établies à partir de renseignements remon- tant loin en arrière et peuvent être modifiés pour des périodes de 7 jours ou des périodes de 3 jours, (modifications à long terme ou court terme) si l'on prévoit des anomalies climatiques pour la durée visée.

Un quatrième concept actuellemant à l'étude utilise la méthode "Champ par champ" et l'étend à un projet d'irrigation complet. Les besoins en eau seront calculés et répartis dans le système d'irrigation, à partir d'un réservoir ou d'un canal, pour être fournis au champ du fermier de cette façon on pourra prévoir les périodes de pointe, établir les possibilités du système, et fournir des renseignements sur les moyens de traiter ces différents problèmes.

L'établissement de plans pour l'irrigation va devenir de plus en plus important puisque l'accroissement de la population exige une augmentation des produits nutritifs. On aura besoin de plus en plus de bureaux qualifiés dans le contrôle de l'irrigation si l'on veut que les ressources en eau soient au mieux utilisées.

INTRODUCTION

This paper describes the role and purpose of irrigation scheduling fo optimum water management, and the characteristics of a professional irriga tion management service that is rapidly gaining acceptance in the wester United States.

Optimum irrigation water management generally requires regulating th soil-water reservoir so that it is never depleted so much that crop growth significantly affected. The manager of an irrigated farm is responsible fo managing a reservoir—the soil-water or root-zone reseroir—from which th rate of withdrawal by evapotranspiration is neither readily apparent nor ca the rate of withdrawal be controlled. Furthermore, the level or content the soil-water reservoir is not visible; it can only be determined directly, b gravimetric soil samples, or indirectly, by using one of several complicated instruments. Thus, optimum water management is difficult to achieve.

The soil-water-atmosphere system is complicated. When soil water is not limiting and there is a complete green crop cover, the rate of evapotranspiration is controlled almost completely by climatic conditions. When soil water is not limiting but only a partial crop cover exists or a crop is approaching maturity, climatic, soil and crop conditions influence evapotranspiration. In many areas, rainfall plays a significant, but uncontrolled role.

Besides the usual skills necessary for normal farming operations to achieve optimum water management, the manager of an irrigated farm must understand soil-moisture flow, meteorology, soil-water-plant growth interactions, hydraulics of the irrigation system and of overland flow, and the interactions of all of these factors within the constraints of his irrigation system. The alternative to these demanding requirements is to obtain professional irrigation management services. The alternative becomes more attractive when institutional constraints, or indirect effects of poor management are involved. For example, the goal of optimum water managements may be to maximize the net return per unit area while maintaining a favourable salt concentration in the soil solution, but restraints may be imposed on the quantity of deep percolation and saline return flow. When a country has very limited water supplies, and society demands maximum food production, the timing and amounts of irrigation water applied must be optimized to limit evapotranspiration without significantly limiting plant growth. Under these conditions, the farm manager must attempt to maximize production per unit volume of irrigation water, or consider the potential increase in production from the next increment of water to be applied. Similarly, when water is not limiting, but its cost is a major factor in crop production, the farm manager must attempt to maximize net returns per unit volume of water used.

Since optimum water management objectives depend on the optimizing goals, optimum water management is more complicated than merely distributing irrigation water, without large losses, through the canal system to the various farms. A canal system is not efficient if it efficiently conveys the wrong quantity of water at a particular time for throughout the season (Olivier, 1972).

Irrigation scheduling will become increasingly more important as food production must be increased to keep pace with population growth. Professional irrigation management services, using the latest advances in irrigation science and technology, will be needed to fully implement optimum water management practices.

IRRIGATION SCHEDULING

PURPOSE

The purpose of irrigation scheduling is to effectively implement a strategy with one or more specific goals of maximizing yields, net returns and water-use efficiency, or minimize indirect adverse effects. Irrigation scheduling to attain a specific goal requires a full understanding of the complicated crop-soil-atmosphere system, so that water is provided when needed based on technical fact and experienced judgement, rather than on historic schedules or arbitrary rules.

SCOPE

Irrigation scheduling predicts when to irrigate and the amount of water to be applied. Irrigations must be scheduled within the constraints of the existing irrigation system and within the ability of the farm manager and his labor force to respond. An irrigation scheduling service supplies the farm manager with data on the current status of the soil-water reservoir, the expected rate of withdrawal to a critical level or the date of the next irrigation, and the amount of water that should be applied to refill this reservoir.

ALTERNATIVE METHODS

The method described in this paper is to schedule irrigations based on the measured or estimated soil-water status, and to predict dates when soil-water will be depleted to desired or critical levels. This method is usually accompanied by inspecting field conditions using trained technicians to verify predictions, and observing other management problems, such as non-uniform water applications, infiltration problems, or malfunctioning irrigation equipment. The traditional approach to improving water management is to first train the farm manager to understand soil-water-plant relationships so that he can schedule irrigations using various tools, such as tensiometers, soil-moisture blocks, evaporation pans, manual soil sampling augers and tubes. This approach has been tried in many areas, but with little success. Irrigations also can be scheduled following historical practices, rigid calendar intervals, or by general field observations; but this approach seldom results in optimum water management.

PROGRESS

Evaluations of farm irrigation practices during the 1960's in the western United States (Tyler et al. 1964; and Willardson, 1967) showed that irrigation scheduling practices changed little during the 25 years since Israelson (1944) made similar evaluations in the late 1930's and the early 1940's. These studies indicated the improvements in irrigation scheduling or techniques to optimize water management were not keeping pace with new developments in irrigation technology. Research studies were begun in 1966 at the Snake River Conservation Reseatch Center, ARS, USDA, Kimberly, Idaho, to develop new techniques for modernizing and significantly improving irrigation scheduling (Jensen, 1969; Jensen et al. 1970). The general progress and the results of wide-spread efforts, following the initial effort in this area, are summarized in this paper. Additional detail can be found in papers by Brown and Buchheim (1971), Jensen et al. (1971), and Jensen (1972).

NEED FOR IRRIGATION MANAGEMENT SERVICES

A typical example of the need for improved irrigation scheduling practices is depicted in Figure 1. In this case the observations represent a field of corn with 255 mm (10 inches) of available soil water capacity. The high soil water levels at the second and third irrigations apparently were not

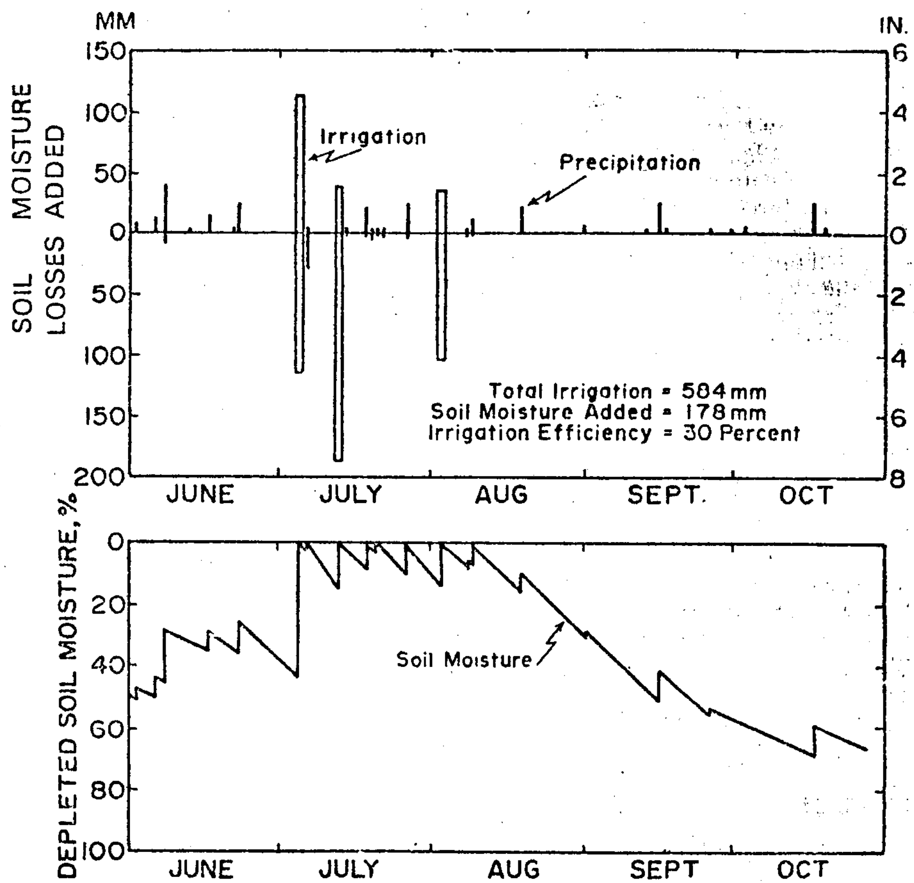

FIGURE 1: Measured irrigation applications and computed soil moisture status on an irrigated cornfield—irrigation efficiency of 30 per cent, McCook, Nebraska, 1966. (Reference 2)

considered or recognized by the irrigator. Surface runoff and deep percolation losses were excessive with irrigation applications of 229 and 127 mm (9 and 5 inches) for the second and third irrigations, respectively, and the irrigation efficiency for the season was only 30 per cent.

By eliminating one irrigation, the seasonal irrigation efficiency could be increased to 60 per cent. This would reduce both labor and water required. The simulated soil-water status, irrigations applied, and precipitation are presented in Figure 2.

3. IRRIGATION MANAGEMENT SERVICES

OBJECTIVES

The primary objective of an irrigation management service is to provide the irrigator or manager of an irrigated farm with current data concerning

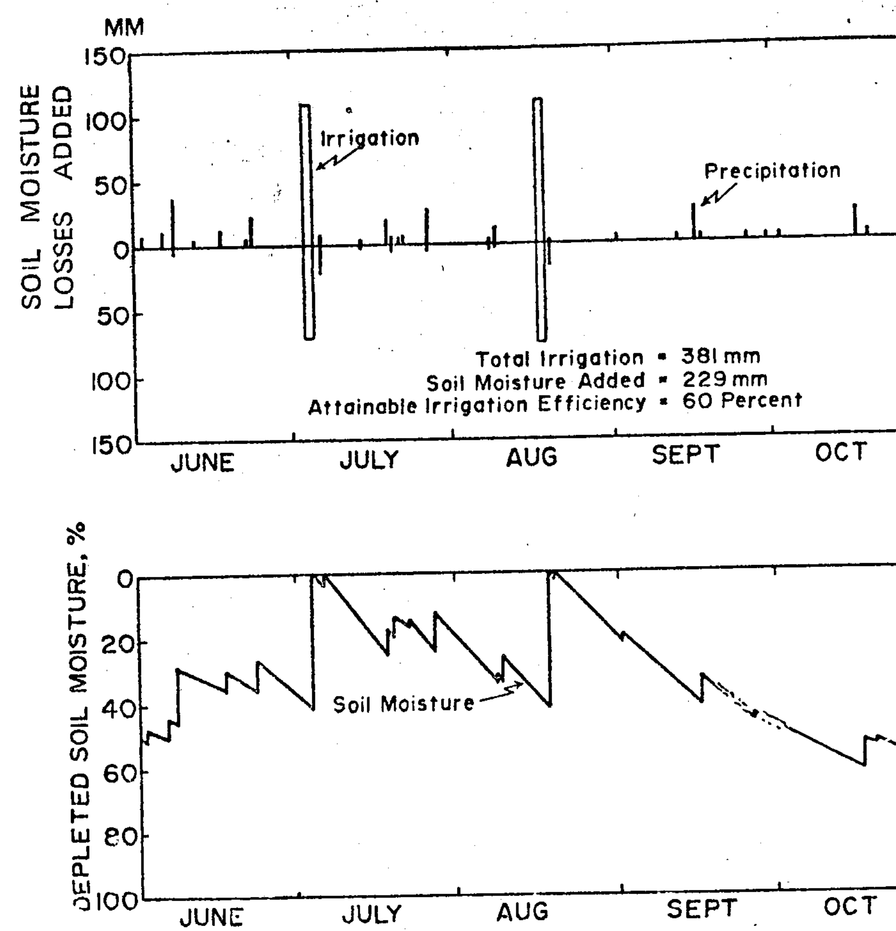

FIGURE 2: Potential improvement in irrigation efficiency by scheduling irrigations at 4 per cent depleted soil moisture on the irrigated cornfield depicted in Figure 1- attainable irrigation efficiency without additional labor is 60 per cent, McCoo Nebraska, 1966. (Reference 2).

the soil-water status of each of his fields at an economical cost. The pri cipal goal of this service is to enable the farm manager to increase the n returns from his irrigation enterprise, or maximize net returns. Increase net returns can be realized by increasing production without significant increasing associated costs, or in some cases, by maintaining production b lowering a sociated o ts.

NEED

A comprehensive study of water use on Federal irrigation projects, begu during the 1960's, clearly indicated at an early stage that farm operato either lacked the necessary information to optimize water management did not understand the proper timing and amounts of water to be applie

Overall conclusions indicated that, on surface irrigated fields only about 45 per cent of the irrigation water delivered to the farm during the irrigation season was available for evapotranspiration through storage in the root zone. It was apparent that irrigation efficiency could be increased to 55 per cent with minor changes in water management using existing facilities, without additional labor, and with an estimated cost of about $ 7 per hectare ($ 3 per acre) for information on irrigation scheduling. Efficiency could be increased to 65 per cent with some additional labor and proper water management, using facilities at an estimated cost of $ 20 per hectare ($ 8 per acre). Efficiencies of 70 to 90 per cent could be obtained, using proper irrigation management techniques and improved farm irrigation facilities, at a cost of from $ 17 to $ 198 per hectare ($ 7 to $ 80 per acre), depending on the status of the irrigation system. (Note: These are equivalent annual costs, 15-year life at 6 per cent.) In areas where surface water supplies are scarce and deep percolation losses could not easily be recovered, irrigations could be controlled to reduce excessive deep percolation losses with some increase in surface runoff. The surface runoff would be more readily controllable for reuse and, in many areas, reduction of deep percolation losses would reduce drainage problems.

One of the many practices affecting irrigation efficiency was the practice of irrigating too soon so that the root zone could not retain the minimum amount of water that could be applied by surface irrigation. The data in Figure 3 show that irrigations generally were less than 30 per cent efficient when less than 20 per cent of the available water was depleted. By allowing depletions before irrigating, efficiencies of 50 per cent or more could be attained.

HISTORY OF DEVELOPMENT

By 1968, new irrigation scheduling techniques were being evaluated on 22 farms in Idaho and on 19 farms in the Salt River Project in Arizona, using a computerized irrigation scheduling program (Jensen et al., 1970). In 1969, the Bureau of Reclamation began its Irrigation Management Services (IMS) program on the A&B Irrigation District, Minidoka Project, Idaho (Brown and Buchheim, 1971). By 1973, the IMS program had expanded to three irrigation districts in Idaho, and the Bureau was providing irrigation scheduling data on 35,000 hectares (86,000 acres) of irrigated land. The Bureau of Reclamation's total demonstration and development program in 1973 involved more than 53,000 hectares (130,000 acres) in the following areas:

A & B Irrigation District, Minidoka Project, Idaho
Falls Irrigation District, Minidoka Project, Idaho
Minidoka Irrigation District, Minidoka Project, Idaho
Boise Project, Boise, Idaho
Westlands Water District, Central Valley Project, California
Palo Verde Irrigation District, Blythe, California
Colorado River Indian Reservation, Parker, Arizona.
Wellton-Mohawk, Gila Project, Wellton, Arizona
Grand Valley Area, Upper Colorado River Basin, Colorado

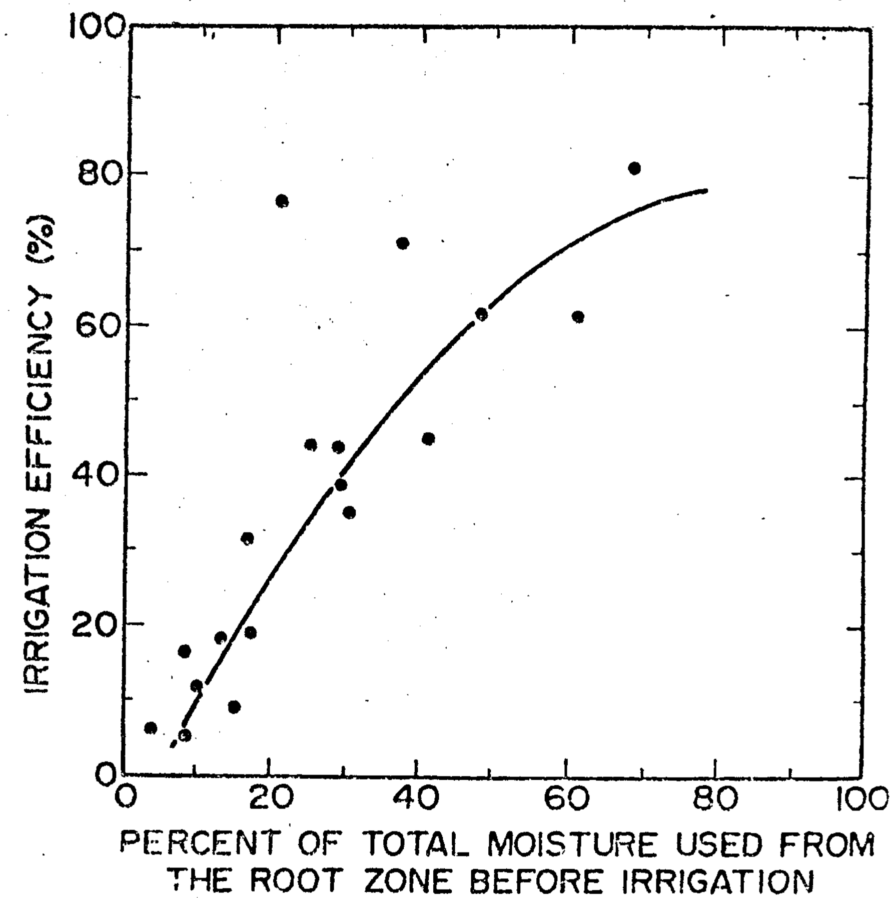

FIGURE 3: Data from a field showing the variation in water application efficiency irrigating at various levels of soil moisture depletion, McCook, Nebraska, 1965-1969. Total available soil water is 255 m (10 inches). (Reference 2)

El Paso Irrigation District, Rio Grande Project, Texas
Las Cruces Irrigation District, Rio Grande Project, Texas
Midvale Irrigation District, Riverton Project, Wyoming
Kansas-Bostwick Irrigation District, Kansas River Basin, Kansas
Pueblo Area- CF&I Farm, Fryingpan-Arkansas Project, Colorado

The Bureau's approach to developing and establishing a viable irrigation scheduling service is to develop and demonstrate techniques that can be adopted by an irrigation district and the irrigators. The irrigator is accepting the new scheduling program because he is directly benefiting from improved crop yields and crop quality, reduced fertilizer requirements, reduced drainage requirements, reduced water costs, and a better allocation of his labor force—all achieved through improved irrigation water management that usually results in more efficient water use.

BENEFITS OF IRRIGATION MANAGEMENT SERVICES (IMS)

Benefits attributable to irrigation scheduling and the IMS program in general have been divided into three categories, reflecting their beneficiaries:

1. *Benefits to the irrigator are:*

   Increased crop yields in quantity and quality.

   Better utilization and/or reduction of labor.

   Better utilization and/or reduction of water.

   Reduced leaching of soil nitrogen and other soluble plant nutrients.

   Fewer restrictions of water deliveries during periods of peak water use.

   Reduced drainage requirements and drainage problems.

2. *Benefits to the irrigation district are:*

   Better utilization of reservoir storage.

   Reduced demand on the delivery system during periods of peak water use.

   Reduced water use.

   Capability to forecast delivery requirements.

   Reduced drainage problems.

   Reduced maintenance requirements.

   Computerized water storage and delivery records.

   Improved economic base associated with the irrigation enterprise.

3. *Benefits to the Region, State and Nation are:*

   Improved economics of irrigated agriculture.

   Reduced adverse environmental effects from irrigated agriculture.

   Improved utilization of the natural resources.

   Improved planning and operational criteria for irrigation.

COSTS AND IMPLEMENTATION METHODS

Because of the demonstration and developmental nature of the Irrigation Management Services program, costs during 1973 were $ 11 per hectare ($ 4.50 per acre) for the areas serviced. Present data and experience indicate that projected costs for large irrigated areas will range from $ 2.50 to about $ 5 per hectare ($ 1 to about $ 2 per acre) per year depending on the level of services provided. All information available in the program shows that the development of an irrigation scheduling service is economically worthwhile to the irrigator and environmentally valuable to the Nation. The Bureau of Reclamation is confident that the irrigators and irrigation districts will ultimately assume full financial support of the irrigation scheduling program. In many situations the program will be operated by an irrigation District. In others, this service may be provided by a private consulting firm. In some instances the Bureau will extend its demonstration program to an operation service under a water users' contract or memorandum of agreement. As the irrigation scheduling program gains acceptance

documented, the involvement of Federal funds will decline. There will t a continuing limited need for general engineering and research funds fc incorporating new technological developments and updating the prograı concepts.

SERVICES PROVIDED

The Bureau is presently providing three levels of irrigation schedulin assistance to the irrigator—the "Irrigation Guide", "Farm Method," an Field by Field." All three methods delegate to the irrigator the final dec sion of when and how much water to apply. The three methods are briefl outlined as follows.

Irrigation Guide. The Irrigation Guide (Table A) gives irrigation inte vals for principal crops in an area based on daily evapotranspiration rat

TABLE A

IRRIGATION GUIDE

Irrigation Guide on timing and consumptive use—A and B irrigation district date of run Sep. 19, 1972

September	12	13	14	15	16	18	17	Forecast
ETP, mm/Day	3.8	3.8	4.6	6.1	6.1	5.8	9.1	5.3
Rainfall mm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	

Irrigation and consumptive use requirements in mm

Crop	*Coef*	*Daily*	*To date*	*Past week*	*Next week*
Sugar beets	0.94	4.8	646	35.1	34.8
Potatoes	0.86	2.8	534	39.1	0.0
Beans	0.47	1.5	540	32.8	0.0
W. grain	0.47	0.0	562	9.7	0.0
Sp. grain	0.47	0.0	491	10.4	0.0

Irrigation interval, optimum depletions, and amount to apply in mm

	Sandy days	*Loam depl*	*soil apply*	*Silt days*	*Loam depl*	*Soils apply*	*Clay days*	*Loam depl*	*Soils apply*
Sugar beets	14	71	117	18	89	147	20	102	168
Potatoes	13	46	0	15	56	0	17	61	0
Beans	12	43	0	14	51	0	17	61	0
W. grain	0	0	0	0	0	0	0	0	0
Sp. grain	0	0	0	0	0	0	0	0	0

ETP = Potential or maximum evapotranspiration for a well watered green referen crop.
Coef = The rate of evapotranspiration as compared to the reference crop.
Days = The normal current internal between irrigations.
Depl = The safe allowable depletion of soil water at current growth stage.
Apply = Depth of water to be applied including system losses

Current Information

(This section is used to provide information that is of immediate use for certai crops) ind average w...-holding capacities for several soils in the area. The guide is updated weekly with daily climatic data from a central location in the area. It gives the average daily water use and the total water use for the week, the total water use to date, and forecasts crop water use for the next week. This information represents a crop with either an early, average, or late planting date for each farm and a stage of growth that is general for the update period in the area. The Irrigation Guide is proving very effective as a supplemental service along with the other irrigation scheduling approaches. Where the data base and experience enable accurate definitions of the general conditions of the area, the recommended irrigation intervals are quite accurate.

Farm Method. The Farm Method (Table B) is substantially more comprehensive than the Irrigation Guide but requires basically the same input data. The data for the Irrigation Guide represent the general irrigated area, whereas the input data for the Farm Method represent a specific irrigator's farm. The Farm Method, like the Guide, requires the irrigator or farm manager to keep good records on precipitation and irrigation events, timing and amounts.

The Farm Method gives the following information for each crop: the average daily evapotranspiration rates; the optimum depletion of soil moisture at the current stage of growth; the total amount of water to apply to the field, considering expected losses and non-uniform distribution of water; the interval between the last two irrigations and the next irrigation; and the need for irrigation, if the last irrigation date was on or before the first date shown, and within 4 days if the last irrigation was on or before the second date. The lower portion summarizes the accumulated depletion for each crop from the seven dates shown and for the season.

As a part of the program, a trained irrigation technician makes regular visits to each farm. The irrigator or the technician must determine if the last irrigation completely replenished the depleted soil moisture and the effectiveness of applying the desired amount uniformly on the field. The technician also works with the irrigator to analyze his irrigation operations. How often the technician must visit depends on the experience, capability, and enthusiam of the irrigator. Experience has shown that visits should be at least weekly during the initial stages of the program. After a year, the visits can be reduced to alternate weeks or longer.

Field by Field. The Field by Field (Table C) concept provides the irrigator or farm manager with the daily soil moisture status of each of his fields in the program. It gives him recommended optimum dates and amounts to apply at the next irrigations. If adequate input data are available, application rates and set times can be included. Because the data requirements are substantially greater than in the other two methods, one field technician is needed for every 2,000 to 4,000 hectares (5,000 to 10,000 acres) served by this program. Techniques and equipment being developed will ultimately expand the area that one man can serve.

The Field by Field scheduling program provides the irrigator with a computer printout once or twice weekly which is considered an "update" of his irrigation program. This update or schedule incorporates the measured climatic parameters during the update period. The update period is the

TABLE B

FARM METHOD

Irrigation Scheduling and water management services—A & B Irrigation District

Date of run July 18, 1972

	July 14	July 15	July 16	July 17	Forecast
Evapotranspiration (*ETP*)	9.7	8.6	8.1	7.9	6.9
Rainfall, mm	0.0	0.0	0.0	0.0	

Field csp	Crop	Coef	Moisture use			Day: Interval		Irr. Req. today if last	This period in 4 days irrig. was.
			Daily	Optimum	Apply	last	next		
122	Alfalfa	1.00	8.1	102	147	13	15	July 06	July 09
222	Sugar beets	0.88	6.6	76	127	11	13	July 08	July 11
322	Potatoes	0.88	6.4	51	71	7	9	July 12	July 14
523	Corn	0.92	6.9	64	97	9	10	July 10	July 13
622	S. Barley	0.51	5.8	107	152	17	26	July 02	July 04
721	W. Wheat	0.51	5.3	122	173	19	30	July 30	July 01

Accumulated Depleitons (mm) since dates below

	Interval (*Days*)	July 16 2	July 14 4	July 12 6	July 10 8	July 08 10	July 06 12	July 04 14	Seasonal totals
122	Alfalfa	15.2	33.3	51.6	65.0	77.7	90.4	103.1	468
222	Sugar beets	12.7	27.2	41.7	54.6	67.1	77.7	89.2	277
322	Potatoes	12.2	25.9	39.9	52.3	62.5	72.6	83.1	193
523	Corn	13.2	27.7	41.9	54.1	67.1	77.7	88.1	194
622	S. Barley	10.7	24.1	37.3	48.5	60.2	72.9	86.9	408
721	W. Wheat	9.7	21.8	34.8	46.7	59.2	72.6	87.4	513

ration potential for 14 days is forecast and updated with each irrigation schedule. This forecasted evapotranspiration potential is based on long-term historic data and can be modified by a long-term (more than 7 days) and/or short-term (3 days or less) adjustment for anticipated climatological anomalies during the forecast period. Along with these climatic data are included a listing of the various fields that would make up a farm or like operational unit. Data included in this list are the crop coefficients for each crop, which represent the crop's stage of growth, and are used to estimate evapotranspiration for each crop from the calculated evapotranspiration potential. Also, soil moisture status for each field is estimated at the beginning and the end of the update period. The end of the update period is the date of the update. Other items included are the effective root zone and the water-holding capacity for that zone, along with the recommended allowable depletion. These data are followed by the date of the last irrigation and the recommended date for the next irrigation on each field.

FIELD BY FIELD METHOD
El Paso Irr. Dist.
Irrigation Management Services—USBR
July 24, 1972 (Update 17)

Recorded daily climatic data and potential evapotranspiration for the update period

Date	Avg. temp. deg. C	Solar rad. mm/day	Daily ETP mm/day	Effect precip. mm	Wind run km
717	25.6	11.7	7.9	0	199
718	26.4	10.4	6.9	0	119
719	25.3	6.9	4.6	18	94
720	24.2	11.7	7.6	0	140
721	25.0	11.4	7.6	0	166
722	25.8	10.2	6.9	0	131
723	25.6	11.7	7.9	0	150

Forecast potential evapotranspiration mm per day

Date	ETP mm/day	Date	ETP mm/day
724	8.1	731	7.9
725	8.1	801	7.9
726	8.1	802	7.9
727	8.1	803	7.9
728	7.9	804	7.9
729	7.9	805	7.9
730	7.9	806	7.6

L. R. Allison Farms
Farm code 1
Irrigation Scheduling—Field Status as of July 24, 1972

Field and crop code	Field size ha	Dates plant, cover		Crop coef ave	RT ZN m	Hold cap. mm	Allow depl. mm	Depl soil moisture		Irrigations			
								Beg.	End	Last date	AMT mm	Next date	AMT mm
10 Lsc	15	417	803	0.98	1.1	175	104	69	94	705	130	725	157
13 Lsc	15	414	801	1.00	1.4	193	117	15	43	712	180	801	168
17 Lsc	16	329	723	1.03	1.1	175	104	38	69	709	206	728	152
21 Alf	13	310	715	0.63	1.4	208	124	135	58	723	127	803	188
30 Lsc	6	406	728	1.02	1.4	191	114	43	71	709	135	720	170
31 Lsc	6	407	728	1.02	1.1	196	117	38	66	709	142	730	175
35 Alf	6	308	716	0.60	1.1	188	112	84	102	702	203	725	163
47 Lsc	2	408	729	1.01	1.4	206	124	69	97	707	183	727	183
53 Pec	7	320	515	1.01	1.4	236	142	119	76	705	147	801	244

SERVICES UNDER DEVELOPMENT

The three concepts now provided represent three distinct levels of on-farm water management. A fourth concept being developed will take the Field by Field approach and relate it to the entire project or irrigation system's capability. Expected irrigation demands will be calculated and routed through the system from storage or initial diversion to the farmer's field. The system management concept will allow prediction of periods of peak demand, and give consideration to the system's capability, and provide guidance on how to deal with such demands. Under the system management concept, it would be necessary to have most of the area under the Field by Field program.

APPLICATION CONSIDERATIONS

In calculating a soil moisture budget, the computer program can be modified to consider most irrigation decisions that can be adequately defined. The various parameters being considered include optimum depletion levels, water-holding capacities, leaching fractions, soil intake rates, water table contributions, daily climatic variations, precipitation probability, and effective rooting depths. These considerations will provide the farm manager the best soil-plant-water information available, and with sufficient lead time will allow him to make critical management decisions. The major decisions confronting all irrigators are when and how much water to apply at the next irrigations. Making the correct decisions and executing these can greatly affect the irrigators economic objectives. Scientific irrigation scheduling will allow the farm manager to plan the total farm operation with confidence in the projected crop water requirements for the next 14 days.

Utilizing a computer to develop the detailed irrigation schedule requires detailed input data. The ability of high speed computers to sort, store, and process a large volume of data offers other advantages. At the end of the irrigation season or at any interim time, a complete record of these data and associated calculations can be produced for evaluation and future planning of the irrigation operation. When incorporated with economic and yield data, these operational data could also be used to optimize irrigation enterprises.

4. OPERATIONAL REQUIREMENTS

PROFESSIONAL AND SUPPORT STAFF

The number of personnel necessary to provide a comprehensive irrigation scheduling program has been estimated to range from one man for every 800 hectares (2,000 acres) to one man for every 4,000 hectares (10,000 acres). Because of different field sizes, a more realistic estimate of manpower is one man for every 200 fields. In estimating manpower requirements, it is important to consider the amount of water measurement and the degree of water management that is currently involved in the area. The degree of detail to be provided by a scheduling program drastically affects the size of the staff required, to serve an area. For example, the estimates given relate to the Bureau's "Field by Field" approach. If these estimates were extended to the "Farm Method" or "Irrigation Guide", one man could serve as many as 200 farms or 2,000 fields, whichever is greater.

Major consideration in staffing an irrigation scheduling operation must be given to the interdisciplinary nature of the program. It would be very difficult to find an individual fully capable of dealing with all aspects of a comprehensive program, and therefore, a team approach is essential to develop a good water management program. A team approach will allow selection of individuals with complementing technical backgrounds and varying levels of participation. A typical team that could serve an estimated 40 hectares (100,000 acres) would be:

1 Agricultural Engineer (crop water requirements and on-farm irrigation systems including water measurement)

1 Hydraulic or Civil Engineer (water delivery systems, water measurement in canals and laterals and computer operations)

1 Soil Scientist or Agronomist (soil and crop characteristics, soil-plant-water relationships and plant nutrition requirements)

7 Fieldmen (soil and climatic data collection)

Any one of the professional members could be replaced by a qualified, trained, and experienced technician. The operator of the computer would depend on the individual best trained in computer technology. Of equal importance to the technical capability in developing the team is the ability of the team to communicate with the farm managers and irrigators. The success of this program lies in the ability of the team to establish communications with the irrigator and maintain the irrigator's confidence in the program, or the goals of the program will not be achieved.

INPUT DATA REQUIREMENTS

In beginning a computerized irrigation scheduling program the first step is collecting field data necessary to develop a daily water budget for the fields to be scheduled. This requires soil parameters, principally the soil water-holding capacity by depth to maximum rooting depth where infiltration rates could be restrictive or where shallow water table, and thickness of the capillary zone should be evaluated. In many areas, these data are available from research publications. Typically, information on each field

contains farm and field codes, field size, representative soil types, water-holding capacities per unit depth to the maximum expected rooting depth, estimated field irrigation efficiency, depth to water table, and capillary zone. The basic crop data required for each field at the start of the irrigation season includes the crop to be grown, its anticipated planting date, estimated full cover date, and allowable soil-water depletion or optimum depletion by growth stages, and the maximum depletion possible for each soil-crop system.

Crop growth and the soil-water level should be monitored periodically, and the data files updated as necessary to maintain the desired accuracy in the schedules. Planting, effective cover, and harvest dates that initially were estimated should be revised as they occur. Another parameter subject to seasonal changes is the effective root zone, which expands with crop development. Where necessary, changes in depth of water table should be monitored and the input to the computer modified. Estimated soil moisture levels usually are periodically evaluated on a spot-check basis. Several basic approaches are used, with the "feel method" being the most popular. Using an Oak-field probe or similar soil sampler, a field is probed and its soil moisture estimated by feel and compared to calculated values. This method was proved sufficiently accurate and quite effective when used by experienced fieldmen. Tensiometers, placed in various locations of a field and at different depths, also are used to assess the effectiveness of irrigations and the scheduling program. Gravimetric soil sampling and analysis are used to obtain soil moisture values and to verify historical computer calculations and some of the soil parameters used. Two other soil moisture measurement devices, used in the Bureau of Reclamation's scheduling program, are the neutron probe and the Speedy Moisture Master.

The climatic data collected to update the water budget are daily maximum and minimum air temperatures, dewpoint temperature, daily wind run, and solar radiation. These climatic data represent a climatic region or area, and each farm is assigned to a specific region. Meteorological conditions delineate the climatic regions; for example, a mountain valley may require three climatic regions to cover one project area, while in another area one climatic region may cover several large irrigation projects. Precipitation is a farm parameter, and therefore, differs from the other climatic data. Once these data are available, the irrigation scheduling program can be used to update all schedules.

When beginning an irrigation scheduling program, the exactness of the soil data is not paramount. The best data available are always used, but often the coverage or the accuracy may be less than that desired. Soils maps and research publications are good sources of most of the basic data needed to start the program. During the period of calibration, most of these inaccuracies can be resolved, and as the program continues, there can be further refinements. This is, in fact, one of the real services of the program, the development of a wealth of usable tested data.

At the beginning of an irrigation scheduling season, the first requirement is to establish the soil moisture status of each field on the program. This is the reference point from which all soil moisture budgets are calculated until the

Where winter precipitation is adequate to recharge the soil-water reservoir, each field can be assumed to be at field capacity when the soil surface begins to dry. Early seasonal rains may replenish soil moisture deficits at an early growth stage. A preplanting irrigation that has completely recharged the soil-water reservoir is another reference point that can be used. If none of the above can be realized, then the soil moisture status should be determined by field examination or soil sampling.

Once initiated, a comprehensive computerized scheduling program requires periodic field servicing. Field servicing is important from two aspects of the program's operation. The first is to monitor the crop development to evaluate and update the basic input data to the computer. The other aspect is to develop and maintain communication with the irrigator; this is essential to the overall success of the program. The fieldmen should understand the data being supplied and some of the basic assumptions and considerations the computer program uses to develop an irrigation schedule. Similarly, the fieldmen should understand the irrigator's problems. This is especially important during the demonstration period of the irrigation scheduling program, when fieldmen may initially visit the farm twice a week. As the irrigator becomes familiar with irrigation scheduling and as the computer program is tailored and refined to the irrigator's operation, the visitation interval may be increased to a month. Refinements include adjusting the operational irrigation efficiency for changes in techniques or methods of applying irrigation water. It also could include timely changes in the irrigation schedule to enable cultural practices, such as applying fertilizers or insecticides, and seasonal adjustments to consider water supply limitations, and special events, such as equipment breakdown.

EQUIPMENT NEEDED

The most obvious piece of equipment needed to operate this irrigation scheduling program is a digital computer. A computer can be accessed by any location in the United States that has telephone service. Today's largest and most modern computers can be utilized by using a remote terminal and the telephone system. Remote access can be expanded to include a high-speed printer, card reader, and magnetic tape unit. Computer service can also be obtained by buying time on local computers that are being operated by educational institutions and private organizations. In one of the Bureau of Reclamation programs, input data are transmitted by telephone several hundred miles to the computer and then the schedules are mailed to the irrigators. Having less than 48 hours of turn-around time is an important aspect of the computer service. Smaller irrigated projects may be able to use programmable desk-type electronic calculators and operate the program by stages.

Only one climatic station may be needed per climatic region. The climatic station should include an anemometer, hygrothermograph (with a sling psychrometer for periodic calibrations), maximum and minimum thermometers, an integrating solar radiation instrument, and a rain-gage. Small simple rain-gages should be supplied to each irrigator to monitor farm rain. Essential laboratory equipment includes soil sampling cans, pressure plate apparatus, bulk density sampler, drying oven, and scales. Water measurement equipment is used to provide data on available flows, runoff [illegible], etc. These may include [illegible], portable weirs, flumes and water stage recorders. The Oakfield Probe and the Speedy Moisture Meter are two essential pieces of equipment which every fieldman carries with him to evaluate the soil-water status. Tensiometers may be used to monitor soil moisture to calibrate the program.

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